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WHEAT FLOUR--A POTENTIAL RAW MATERIAL FOR THE EXPANDED PRODUCTION OF STARCH AND SIRUPS*

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The three most important starches produced in the world are corn, white potato, and cassava starches. These are mainly produced in three widely separated regions of the globe; corn starch in the United States, cassava starch (tapioca) in the Dutch East Indies, and potato starch in Central Europe. In each of these regions the commodity from which the starch is produced not only plays a most important role in the agricultural economy of the area, but also is the cheapest starchy material available.

For the United States, the general relationship of availability and relative cost of starch in the principal cereal grains is shown in table I. The raw-material cost, based on the starch content of the grain, over the 1935-40 period is lower for corn than for any of the other grains except sorghum, which is produced in relatively limited quantities. The utilization of corn as a source for starch is favored by a number of other advantages, in addition to the low cost. Corn is grown in tremendous quantities and is usually in surplus. Only a minor portion of the crop is sold on the cash markets, the major part of it being retained on the farm mainly for feeding purposes. These factors tend to reduce price fluctuations and to ensure an abundant source of raw material for industrial processing. Corn has a comparatively higher oil content than other grains, and, what is more important, the oil is more easily recovered, thus serving as a profitable byproduct. These various advantages thus provide a sound basis for the utilization of corn for starch processing in this country over the long term.

The annual starch production in the United States during the six years prior to 1941, which might be considered normal years, varied from about 2,000 to 2,800 million pounds, of which roughly one-third was sold as such while the remainder was processed further, e.g., to dextrins, glucose sirups, or dextrose. Corn, processed in the wet-milling industry, was the main raw material, accounting for more than 98 percent of the starch produced. The amount of corn used annually by the corn wet-milling industry from 1935-40 varied from 58 to 82 million bushels. Other starches produced in this country during that period were wheat, white potato, sweetpotato, and rice starches. These were produced almost wholly for specialty purposes.

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Since 1941 there has been a tremendous increase in the production of starch and other products by the corn wet-milling industry, the amount of corn processed increasing from 82 million bushels in 1940 to 130 million bushels in 1942. This increase to full-capacity operation to produce starch and its conversion products has been due to a number of factors: (1) an augmented domestic demand for starch products for food and essential industrial uses, (2) exportation of starch products for Lend-Lease purposes, and (3) a sharp decrease in tapioca starch imports, from about 400 million pounds in 1940 to less than 50 million pounds in the past year, because of the occupation of the Dutch East Indies by the Japanese. In spite of the increase to full-capacity operation, the corn wet-milling industry has been unable to satisfy all the demands for its products and a voluntary rationing system has been in effect for over a year. Attempts to increase operations by plant expansion have been essentially unsuccessful owing to the difficulty in obtaining equipment and construction materials. The industry, also, has had to contend with the shortage of corn on the cash market. This became so critical in the summer of 1943 that several plants had to cease operations until corn was made available through measures taken by the War Food Administration.

Because of the shortage of corn, coupled with the necessity of maintaining or increasing starch and sirup production, consideration is being given to the utilization of other cereal grains and to the development of new processes for the production of starch. In addition to availability and price, the use of raw materials, other than corn, is dependent on such considerations as: (1) production of starch of adequate purity in satisfactory yield, (2) recovery of byproducts, particularly protein for feed or commercial uses, and (3) adaptability of the processing methods to existing plant facilities with a minimum of new installations involving critical materials. Types of plants in which starch and sirup could be produced are cane sugar refineries, beet sugar factories, and, possibly, white potato starch plants. The latter two of these industries operate on a seasonal basis and possess many of the facilities required; moreover, some beet sugar factories, because of the unavailability of sugar beets, have been idle during the last year or two.

The domestic commercial grains, namely, wheat, rye, barley, oats, sorghum, and rice are rich in starch, and therefore are possible raw materials for increasing the supplies of starch and its derivatives. Of prime importance in the production of starch are availability and cheapness of raw material. The production, carry-over, and the average cost of these various cereals, and of corn for comparison, for the crop year 1943 are shown in table I. The percentage of starch in each of these cereals and the raw-material cost per pound of starch are also included.

Rice and oats offer little promise for the near future as raw materials for starch production in view of the high cost of the grain per pound of starch. Because of the increased demands for rice as a food and as raw material for the manufacture of beer, the price has risen to a level where it is no longer profitable to produce rice starch at the ceiling price of 9 cents per pound. As a result, the sole manufacturer of rice starch has discontinued operations on its production.

Sorghum has never been produced as a large cash crop in this country. Within the last year there has been intense competition for available supplies of sorghum, which is very similar to corn in many respects, to alleviate the corn shortage among feeders, brewers, and, to some extent, distillers. In the wet-milling of sorghum for the production of starch, the small kernel and the recovery of the germ present processing difficulties. Owing to these disadvantages, the corn wet millers have not used sorghum as a raw material in normal times, even when sorghum was cheaper than corn. Now that the price is approximately the same as that of corn, and because of the negligible supplies available, there is even less incentive to use sorghum as a source of starch.

Economical processing methods for producing rye and barley starches have not, up to the present time, been developed. The presence of relatively large amounts of pentosans or hemicelluloses in these cereals causes excessive foaming, in wet-milling processes, which interferes with the production of starch in a high yield. Patents have been granted on processes based on the use of the flours, but the yield of starch obtained by these procedures is comparatively low. Until these processing difficulties can be overcome and the yield of starch increased, rye and barley are in an unfavorable position as potential raw materials for starch production. A further disadvantage of the use of rye would be the very limited amount grown, the entire 1943-44 crop being equivalent to only one-fourth of the corn processed in 1942 for starch production by the wet-milling industry.

Wheat, from the standpoint of availability, price, and ease of processing, is the closest competitor to corn as a raw-material source for the production of starch, and at the present time shows most promise for expanding the production of starch and sirups. The estimated carry-over of wheat for the current crop year, as shown in table I, is substantially greater than for corn. The corn carry-over, moreover, is of questionable industrial value since it may never reach the cash market, as was the case in 1942-43. In the Pacific Northwest, the production of starch and sirups from wheat appears to be particularly attractive. During the past decade soft wheat has been a burdensome surplus in this region, and its price has approximated, and, in some years, even been less than the Chicago market price of corn.

Wheat at one time was the most important raw material for producing starch. The earliest recorded description of the preparation of starch mentioned the process of fermenting wheat to facilitate the separation of starch. Such procedures were subsequently displaced by the Alsatian process, in which the grain was subjected to prolonged non-fermentative steeping in water. The softened grain was then crushed and the starch washed out of the ground mass. In the last 50 to 100 years, flour, rather than the grain, has been the main raw material because of the ease in processing and of recovering the gluten, a valuable byproduct. Cheaper raw materials, however, have largely displaced wheat in starch production during the last century and a half. In recent years wheat starch has been produced in the United States to a limited extent (perhaps 15-18 million pounds annually), largely for use as a specialty product.

Flour as Raw Material

From the standpoint of simplicity of equipment and operating steps, wheat flour is preferable to the grain as a raw material for producing starch. Because of the elimination of the steeping and grinding steps necessary in wet milling, flours can be processed more rapidly in less plant space. The use of flour also simplifies the problem of byproduct recovery since much of the bran and fiber is separated at the flour mill. A further advantage of flour is its high starch content, straight wheat flour having about 76-81 percent starch (moisture-free basis). Since there is ample milling capacity, the grinding of wheat to flour presents no production difficulties. While flour is a higher-priced raw material, this disadvantage, under present conditions, is probably outweighed by the advantages in favor of the use of flour. The difference between the cost of wheat flour and the grain, calculated on the basis of the starch content only, has decreased well below that of normal years (see table I). This discussion is limited, therefore, to the utilization of flour, particularly from wheat, for starch production.

Methods of Starch Production from Wheat Flour

Relatively little information is available, either in patents or in other publications, concerning the industrial preparation of starch from wheat flour. Most patents relating to starch production deal with wet processing of corn. Some of these patents claim or indicate applicability to wheat or other grains, although it is doubtful if such grains have been used to a significant extent, if at all. For the processes which have been used or proposed for wheat starch production, details are usually lacking on the procedure, on the yields and purity of the products, and on the adaptation of the processing steps to modern methods and equipment.

The processes for the production of starch from wheat flour which have been described in patents may be roughly divided into two groups, the mechanical processes and the chemical processes. The mechanical processes comprise those in which the water-insoluble protein remains as essentially unaltered wheat gluten, the separation of gluten (hydrated water-insoluble protein) from starch being primarily a mechanical problem. The mechanical processes, in general, permit recovery of gluten which is of value for the strengthening of weak flours, for making high-gluten bakery products, or for other purposes requiring a rehydratable wheat gluten. For uses where this property is not required, such as for other food or industrial purposes, the gluten obtained by these processes can be dried at higher temperatures which denature the protein.

In the chemical processes, alkalies, acids, enzymes, or other chemicals are introduced to dissolve or disperse the protein prior to separation of the starch. Such chemical treatment alters the water-insoluble wheat protein so that it loses its glutinous properties and ability to rehydrate. The wheat protein recovered from the chemical processes is of

value for feed and industrial uses. Where only small quantities of some chemicals are used, the properties of the gluten may be largely retained, in which case the treatments are considered under mechanical processes.

Mechanical Processes

The first wheat flour processing method to receive general acceptance was that of Martin (1), described in 1837. Most of the wheat starch now produced in the United States and probably in Europe is being made by this method with technical improvements. The Martin process is essentially the mechanical application, on an industrial scale, of the steps used in the familiar quantitative determination of crude gluten (2) by washing the starch from a dough ball. A stiff dough, after being allowed to hydrate for an hour, is rolled between fluted rolls or kneaded in a trough with reciprocating rolls under a spray of water to wash the starch away from the gluten mass. Starch, from the screened starch milk, is collected by tabling or settling. This procedure is advantageous in providing a high recovery of good-quality gluten in a form easily handled. The processing requires the use of dough-mixing equipment and specially designed dough-washing apparatus. The washing of starch from the dough mass is necessarily slow because of the limited surface exposed to the water at any one time. Increasing the volume of the portion of dough being washed causes a disproportionately great increase in the time required to free the gluten of starch. Large-scale production would be attained, therefore, by increasing the number, rather than the size, of the dough-washing machines. On these grounds the process does not appear to be well-adapted to large-volume starch production.

Numerous variations of the Martin process have been proposed to facilitate or eliminate the dough-washing steps. Gassaway (3) described the preparation of a thin dough in a closed mixer and subsequent addition of more cold water with continuation of the mixing. The starch was then separated from the gluten by drawing the starch milk off through a strainer. Barker (4) recommended the preparation of a semi-fluid mass of flour or granulated cereal with water and forcing this through a perforated plate provided with a cutter. The resulting pieces were stirred gently in water to free the starch from the gluten. The particles of gluten settled in the tank while the starch suspension was drawn off and the starch collected by gravity settling. The centrifugal separation of starch and gluten from a flour paste has been described by Fesca (1), this process being modified by Keil (5) and by Klopfer (6) through the addition of chemicals to aid the separation. The centrifuging does not effect as clean-cut a separation of the components as the dough-washing procedures nor is the yield of starch as high. So far as we know, none of these modifications of the Martin process are now being used.

The Procea process for starch and gluten separation has recently received considerable publicity as a means of preparing gluten which is claimed to be admirably suited to use in bread and other bakery products. As described in patents by Bellingham (7) and by Williams (8),

the process consists of the treatment of a baker's "sponge" with a salt solution so that the gluten floats to the surface and the starch is set free. A similar process has been described by Morea (9), the salt solution being replaced by lime water. The use of such processes in terms of starch production was not discussed, but work done at the Northern Regional Research Laboratory on these processes suggests that they are not of practical importance for large-scale starch production.

Chemical Processes

One of the first processes using alkali for the production of starch was that described by Jones (10) in 1841 for the preparation of starch from rice and from wheat meal. The wheat meal was stirred with dilute alkali for about 12 hours, after which the starch and other insoluble solids were allowed to settle for about 70 hours. The starch was purified by washing and settling in tanks. Protein was recovered from the alkaline liquor by precipitation with sulfuric acid, the precipitate being collected after settling in tanks. While wheat or wheat flour has probably been processed by such treatment, practically no information is now available on the industrial application of the process. The use of corn in the United States for starch production was widespread at the time that the Jones process was introduced. As a result, the alkali treatment was adopted in connection with the making of corn starch rather than wheat starch, and was widely used until replaced by the sulfurous acid steep.

The use of proteolytic enzymes for the dissolution of the protein has been suggested by Campbell (11) and by Klopfer (12), but these proposed methods apparently have never received serious consideration.

Chemical processes have probably not been used to any great extent during the past 50 years for the production of any starch except rice starch. In recent times rice starch has been manufactured on a small scale by a procedure essentially similar to that described by Jones. Chemical processes for producing wheat starch have lost favor chiefly because the protein is denatured or lost. The principal advantage offered by the chemical processes, in general, appears to have been the more complete removal of protein from the starch by relatively simple treatment.

Process Development at the Northern Regional Research Laboratory

More than a year ago, when it became apparent that a shortage of corn, starch, and sirups and other sweetening agents existed, investigations were initiated on the development of new processes or adaptations of old ones for the production of starch from wheat flour. Emphasis was placed on the development of procedures that would involve a minimum of equipment or that would be adaptable to existing plant facilities. As a result of these studies two simple processes have been developed; namely, the Alkali Process and the Batter Process.

Alkali Process

This process is dependent on the protein-dispersing action of dilute alkali and permits the recovery of all the starch. The first step in the process involves simply the stirring of the flour with dilute alkali. In about N/30 sodium hydroxide the protein is dispersed at room temperature very rapidly and quite completely. Other alkalies can also be used, but sodium hydroxide gives better results than most and is cheap and easily available. Under these weakly alkaline conditions, starch undergoes no change excepting that due to cation exchange, which causes minor changes in a few of the properties such as the viscosity of the starch paste and the ease of dextrinization of the starch.

The second step in the process entails the separation of the starch from the alkaline-protein liquor. This can be effected either by gravity settling on tables as practiced in the corn wet-milling industry or by centrifugation. In the former method of separation, starch is obtained in two fractions. The denser material, constituting 70-80 percent of the starch present in the flour, is collected on the table and is called "table starch". The remainder of the starch which settles more slowly passes over the tail of the table and is known as "tailing starch". Table starch, after screening through silk bolting cloth to remove particles of bran and cell-wall fibers, and washing to remove the associated alkaline-protein liquor, is of prime quality, being comparable in purity to the highest grade cereal starches commercially available. Tailing starch consists essentially of the small-granule fraction of wheat starch and is recovered from the tailings by centrifugation. Tailing starch is not quite as pure as table starch and is difficult to obtain in a dry, pulverulent condition. The prime-quality starch may be used as such or converted into dextrose or high-quality sirups. The lower-quality tailings starch is suitable for fermentation or conversion into glucose or malt sirups. When all the starch is collected by centrifugation there is associated with it alkali-insoluble material such as fiber. This product therefore is not of prime quality and is preferably used, while still wet, for fermentation purposes or for conversion to sirups.

Byproduct protein can be recovered by centrifugal collection of the precipitate produced on acidification of the starch-free alkaline solution. From 50 to 80 percent of the wheat-flour protein having a purity of 60 to 90 percent is recovered. This protein has undergone some chemical alteration since it has lost the glutinous properties of "native" wheat gluten. Industrial tests have shown that the recovered protein from the alkali process can be used for the production of monosodium glutamate.

Batter Process

This mechanical process is based on the cohesive property of hydrated gluten which permits individual gluten particles in the flour to be collected into a coherent mass. Flour is converted to a batter which differs from the dough used in the Martin's process in that it contains

several times as much water. The batter is thin enough to flow, and, due to the greater hydration of the gluten, is readily broken up in water. On disintegration of the batter a large surface is exposed from which the starch can be washed out quickly. During this operation the gluten is retained in the form of curds which can be separated easily by screening.

The process, in general, comprises: (1) the mixing of flour and water until a uniform elastic batter is produced in which the hydrated gluten particles are substantially in the form of a continuous gluten network enmeshing the starch granules, (2) the simultaneous washing of the starch out of the batter and the production of gluten curds by mechanical disintegration of the batter in water, (3) the separation of the gluten curds from the starch milk by means of a vibrating or gyratory screen, and (4) further refining of the starch and crude byproduct gluten according to end-use requirements. The starch milk as it comes through the screen may be used directly for fermentations or conversion to sirups. The starch may be further refined as described under the alkali process to serve the purposes indicated there.

The crude gluten coming over the end of the screen, and containing about 75 percent protein, dry basis, may be dried at low temperatures to give undevitalized gum gluten suitable for fortifying low-protein flour for bread making or utilization in other food products. Drying at higher temperatures, as on a drum drier, yields a product suitable for food products, stock feed, or industrial uses.

If required, gluten containing up to 95 percent protein may be prepared by comminuting the wet gluten in water to remove most of the 15 to 20 percent starch present. This purified gluten may be dried also as indicated above.

Evaluation of Processes

From the standpoint of quantity and quality of starch produced, the two processes described are about equal. Although the processes serve substantially the same purpose, each does enjoy certain advantages as regards applicability to raw materials and type of products produced.

The alkali process is advantageous in its applicability to a wide variety of raw materials. Straight and clear grades of flour from all varieties of both soft and hard wheat may be used, while granular wheat flour is suitable when the centrifugal rather than the tabling separation is used. Rye, barley, oat, and rice flours may also be processed in essentially the same manner, although the recovery of byproduct protein is usually less satisfactory.

The batter process has been found applicable to all types of wheat flours or ground wheat except those having the very lowest protein content. The advantages of this process lie in the speed and simplicity of operation, requirement of no chemicals, and practically complete recovery of the wheat gluten in undevitalized state. This process has not been found applicable to either rye or corn flours.

The amount and kind of equipment needed for either process will vary according to the type of products produced and the degree of refinement required for the projected end-use of these products. The lease amount of equipment would be required, for example, in producing starch slurries or wet starch without further refining. Such a product could then be used for fermentation purposes or for the production of less highly refined sirups. These processes could therefore be used advantageously in plants where the facilities are already available for the fermentation or for processing the starch conversion products.

The alkali and batter processes can be used advantageously in beet sugar factories and sugar refineries for the production of starch for conversion into sweetening agents. The amount of new installations required would be greatly reduced since these plants already contain nearly all the equipment necessary for the processing of the starch conversion liquors in the production of sirups. Since beet sugar factories operate seasonally, the production of sirups could be carried out during the off-season, permitting year-around operation of the plants. It is for this type of application that these processes appear particularly feasible.

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(10) Jones, Orlando, U. S. Patent 2,000 (March 12, 1841).

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Table I
Availability and Relative Cost of Starch in Various Domestic Cereals

Commodity	Grade	1943 Av. price per bushel	Starch content as purchased 1/	1943 Cost of raw material containing 1 lb. starch	1943 Cost of starch relative to corn 2/	1935-40 Av. cost of raw material containing 1 lb. starch	1935-40 Av. cost of starch relative to corn 2/	Total supply of grain 8/ (all grades)	Carry-over at end of crop year 9/
		Dollars	Percent	Cents	Ratio	Cents	Ratio	Millions of lbs.	Millions of lbs.
Corn	No. 3 Yellow 3/	1.06 10/	68	2.8	1.0	1.8	1.0	193,100	11,100
Wheat	No. 2 Hard Red Winter 4/	1.44	64	3.8	1.4	2.5	1.4	87,200	17,900
Wheat flour	Straight, Hard Red Winter 4/	3.17 (per 100 lb.)	79	4.0	1.4	3.2	1.8		
Rye	No. 2 5/	.95	57	3.0	1.1	1.9	1.1	4,100	2,600
Barley	No. 3 5/	1.24	60	4.3	1.5	2.3	1.3	20,600	1,900
Oats	No. 3 White 3/	.85	40	6.6	2.4	2.7	1.5	44,200	3,800
Grain sorghum	All 6/	1.04	66	2.8	1.0	1.5	.8	5,900	100
Rice	Rough 6/	1.76	67	5.8	2.1	2.5	1.4	2,900	7/

1/ Approximate values, calculated as commercial starch (11 percent moisture) in the raw material having 13.5 percent moisture.
2/ Disregarding the manufacturing costs and value of byproducts. 3/ At Chicago. 4/ At Kansas City.
5/ At Minneapolis. 6/ At the farm. 7/ Not available.
8/ The grain supply is the summation of the 1943-44 crop production and the carry-over from the previous crop.
9/ These are estimated carry-overs for the end of the 1943-44 crop year, except for rye and grain sorghum, for which the carry-over at the end of the 1942-43 crop year is given. For 1943-44, the farm production, however, of rye was substantially lower than the disappearance of the previous year; with similar consumption the carry-over at the end of the present crop year will be much lower.
10/ During the last half of 1943 almost no cash sales of corn were recorded at Chicago. The ceiling price in October for the 1942 crop was $1.06, and the 1943 crop corn ceiling was $1.07 in November and $1.16 per bushel in December.